

#### SCOPE OF CLAIMS

1. An apparatus for controlling a legged mobile robot which is movable by repeating lifting and then landing actions of each of a plurality of legs, comprising:

foot landing position/orientation estimating means for estimating a landing position and landing orientation of the foot of each of the legs which is landed in each landing action of the robot;

desired path setting means for setting a desired footstep path for the robot;

desired foot landing orientation determining means for determining a desired landing orientation of the foot which is landed in at least either one of subsequent landing actions of the robot in order to cause actual footsteps of the robot to approach said desired footstep path based on at least said estimated landing position and landing orientation of the foot and said desired footstep path;

desired gait determining means for determining a desired gait for the robot using at least the desired landing orientation determined by said desired foot landing orientation determining means; and

operation control means for controlling operation of the robot depending on the determined desired gait.

2. An apparatus for controlling a legged mobile robot according to claim 1, characterized in that said desired landing orientation comprises an orientation about a

vertical axis, and the landing orientation estimated by said foot landing position/orientation estimating means includes at least an orientation about a vertical axis.

3. An apparatus for controlling a legged mobile robot according to claim 1, characterized in that said legged mobile robot comprises a biped mobile robot having two legs, the desired landing orientation determined by said desired foot landing orientation determining means includes at least a desired landing orientation of the foot which is to be landed in a next time's landing action of the robot and a desired landing orientation of the foot which is to be landed in a next but one time's landing action of the robot, and said desired gait determining means determines a desired gait which defines the next time's landing action of the robot using at least said desired landing orientation determined by said desired foot landing orientation determining means for said next time's landing action and said next but one time's landing action.

4. An apparatus for controlling a legged mobile robot according to claim 1, characterized in that said desired foot landing orientation determining means determines a desired landing position for the foot which determines said desired landing orientation, together with said desired landing orientation, based on at least the landing position and landing orientation of the foot estimated by said foot landing position/orientation estimating means and

said desired footstep path, and said desired gait determining means determines said desired gait using the desired landing position and the desired landing orientation which are determined by said desired foot landing orientation determining means.

5. An apparatus for controlling a legged mobile robot according to claim 4, characterized in that said desired foot landing orientation determining means comprises means for determining a desired landing orientation about a vertical axis and a desired landing position of the foot which is to be landed in at least several landing actions ahead including a next time's landing action, based on at least said landing position and landing orientation estimated by said foot landing position/orientation estimating means and said desired footstep path, said desired gait determining means comprises means for determining a desired gait which defines the next time's landing action using at least the desired landing position and desired landing orientation of the foot in the several landing actions ahead, which are determined by said desired foot landing orientation determining means, and said desired foot landing orientation determining means determines a combination of a desired landing position and a desired landing orientation of the foot within a self-dependent allowable landing range determined under mechanism-dependent limiting conditions of the robot itself, which include an interference between the

leg making the next time's landing action and the other leg, when a desired landing position and a desired landing orientation of the foot corresponding to at least the next landing action are to be determined.

6. An apparatus for controlling a legged mobile robot according to claim 5, characterized in that said self-dependent allowable landing range is set based on a map or formula which is determined in advance as defining a relative allowable landing range of the foot to be landed in the next time's landing action, with respect to the foot landed in the landing action.

7. An apparatus for controlling a legged mobile robot according to claim 5, characterized in that said desired gait determining means comprises means for provisionally determining a desired ZMP in said desired gait which defines said next time's landing action using at least the desired landing position and desired landing orientation determined by said desired foot landing orientation determining means, and said desired foot landing orientation determining means corrects at least either one of said desired landing position and desired landing orientation of the foot to be landed in at least either one of said several landing actions ahead when the provisionally determined desired ZMP does not satisfy predetermined limiting conditions.

8. An apparatus for controlling a legged mobile robot according to claim 4, characterized in that said legged mobile robot comprises a biped mobile robot having two legs, said desired landing position for the foot comprises a representative point having a predetermined positional relationship to each foot and a desired position for a representative point which is determined in advance with respect to each foot such that the representative point with respect to each foot becomes an identical point for both feet when said robot is upstanding in a predetermined reference symmetrical posture, and said desired footstep path comprises a path to be approached by said representative point.

9. An apparatus for controlling a legged mobile robot according to claim 8, characterized in that said representative point comprises a point set up near the heel or toe of each foot.

10. An apparatus for controlling a legged mobile robot which is movable by repeating lifting and then landing actions of each of a plurality of legs to determine a desired gait, control operation of said robot depending on the desired gait, determine a hypothetical periodic gait following a new desired gait when the new desired gait is determined each time the foot of each leg of the robot is landed in at least each landing action of the robot, and

determines the desired gait so as to approach the periodic gait, comprising:

foot landing position/orientation estimating means for estimating a landing position and landing orientation of the foot of each of the legs which is landed in each landing action of the robot;

desired path setting means for setting a desired footstep path for the robot;

desired foot landing position/orientation provisionally determining means for provisionally determining a desired landing position and desired landing orientation of the foot which is landed in at least either one of subsequent landing actions of the robot based on at least either one of a latest desired gait and said periodic gait corresponding to the desired gait, and the estimated landing position and landing orientation of the foot;

desired foot landing position/orientation correcting means for correcting at least either one of the provisionally determined desired landing position and desired landing orientation in order to cause actual footsteps of the robot to approach said desired footstep path based on the provisionally determined desired landing position and desired landing orientation and said desired footstep path; and

desired gait determining means for determining said new desired gait for the robot using at least the cor-

rected desired landing position and desired landing orientation.

11. An apparatus for controlling a legged mobile robot according to claim 10, characterized in that said desired landing orientation comprises an orientation about a vertical axis, and the landing orientation estimated by said foot landing position/orientation estimating means includes at least an orientation about a vertical axis.

12. An apparatus for controlling a legged mobile robot according to claim 10, characterized in that said desired gait determining means comprises means for provisionally determining a desired ZMP in said new desired gait using at least the desired landing position and desired landing orientation corrected by said desired foot landing position/orientation correcting means, and said desired foot landing position/orientation correcting means corrects at least either one of said desired landing position and desired landing orientation in at least either one of said several landing actions, which has been provisionally determined by said desired foot landing position/orientation provisionally determining means, when the provisionally determined desired ZMP does not satisfy predetermined limiting conditions.

13. An apparatus for controlling a legged mobile robot according to claim 10, characterized in that said legged mobile robot comprises a biped mobile robot having

two legs, said desired landing position for the foot comprises a representative point having a predetermined positional relationship to each foot and a desired position for a representative point which is determined in advance with respect to each foot such that the representative point with respect to each foot becomes an identical point for both feet when said robot is upstanding in a predetermined reference symmetrical posture, and said desired footstep path comprises a path to be approached by said representative point.

14. An apparatus for controlling a legged mobile robot according to claim 13, characterized in that said representative point comprises a point set up near the heel or toe of each foot.

15. An apparatus for controlling a legged mobile robot which is movable by repeating lifting and then landing actions of each of a plurality of legs, comprising:

foot landing position/orientation estimating means for estimating a landing position and landing orientation of the foot of each of the legs which is landed in each landing action of the robot;

allowable foot landing range setting means for setting a plurality of environment-dependent allowable landing ranges corresponding to several landing actions ahead which include at least next time's and next but one time's landing actions, of environment-dependent allowable



landing ranges determined under environmental conditions in which the robot moves, which are allowable ranges of combinations of landing positions and landing orientations of feet landed in the landing actions of the robot;

desired foot landing position/orientation determining means for determining combinations of desired landing positions and desired landing orientations of feet to be landed in said several landing actions ahead in order to satisfy the environment-dependent allowable landing position ranges, based on at least said estimated landing orientation of the foot and a plurality of environment-dependent allowable landing position ranges set by said allowable foot landing range setting means;

desired gait determining means for determining a hypothetical periodic gait of the robot using at least the determined desired landing positions and desired landing orientations corresponding to the determined several landing actions ahead, and determining a new desired gait for the robot which defines at least the next time's landing action in order to approach the determined hypothetical periodic gait; and

operation control means for controlling operation of the robot depending on the determined new desired gait.

16. An apparatus for controlling a legged mobile robot according to claim 15, characterized in that said

desired landing orientation comprises an orientation about a vertical axis, and the landing orientation estimated by said foot landing position/orientation estimating means includes at least an orientation about a vertical axis.

17. An apparatus for controlling a legged mobile robot according to claim 15, characterized in that said desired foot landing position/orientation determining means determines a combination of a desired landing position and desired landing orientation for the foot in at least the next time's landing action within a common region of a self-dependent allowable landing range determined under mechanism-dependent limiting conditions of the robot itself, which include an interference between the leg making the next time's landing action and the other leg, and the environment-dependent allowable landing range corresponding to the next time's landing action, and said desired gait determining means uses the desired landing position and desired landing orientation for the foot to be landed in at least the next time's landing action in order to determine said hypothetical periodic gait.

18. An apparatus for controlling a legged mobile robot according to claim 17, characterized in that said self-dependent allowable landing range is set based on a map or formula which is determined in advance as defining a relative allowable landing range of the foot to be landed

in the next time's landing action, with respect to the foot landed in the landing action.

19. An apparatus for controlling a legged mobile robot according to claim 15, characterized in that said desired gait determining means comprises means for provisionally determining a desired ZMP in the desired gait for the robot which defines at least said next time's landing action, and said desired foot landing position/orientation determining means corrects at least either one of said desired landing position and desired landing orientation of the foot to be landed in at least either one of said several landing actions ahead when the provisionally determined desired ZMP does not satisfy predetermined limiting conditions.

20. An apparatus for controlling a legged mobile robot according to claim 15 or 17, characterized in that said legged mobile robot comprises a biped mobile robot having two legs, and said desired landing position for the foot comprises a representative point having a predetermined positional relationship to each foot and a desired position for a representative point which is determined in advance with respect to each foot such that the representative point with respect to each foot becomes an identical point for both feet when said robot is upstanding in a predetermined reference symmetrical posture.

21. An apparatus for controlling a legged mobile robot according to claim 20, characterized in that said representative point comprises a point set up near the heel or toe of each foot.

22. An apparatus for controlling a legged mobile robot which is movable by repeating lifting and then landing actions of each of a plurality of legs, comprising:

foot landing position/orientation estimating means for estimating a landing position and landing orientation of the foot of each of the legs which is landed in each landing action of the robot;

first allowable landing range setting means for setting a plurality of environment-dependent allowable landing ranges corresponding to several landing actions ahead which include at least next time's and next but one time's landing actions, of environment-dependent allowable landing ranges determined under environmental conditions in which the robot moves, which are allowable ranges of combinations of landing positions and landing orientations of feet landed in the landing actions of the robot;

second allowable landing range setting means for setting a self-dependent allowable landing range for a combination of a landing position and landing orientation of the foot to be landed in the next time's landing action, based on a desired landing position and desired landing orientation of the foot in each landing action which are

estimated by said foot landing position/orientation estimating means and mechanism-dependent limiting conditions of the robot itself, which include an interference between the leg making the next time's landing action and the other leg;

desired foot landing position/orientation determining means for determining a combination of a desired landing position and desired landing orientation of a foot to be landed in the next time's landing action within a common region of the environment-dependent allowable landing range and the self-dependent allowable landing range which are set respectively by said first allowable landing range setting means and said second allowable landing range setting means for at least said next time's landing action, based on said environment-dependent allowable landing range and said self-dependent allowable landing range;

desired gait determining means for determining a desired gait which defines the next time's landing action using at least the determined desired landing position and desired landing orientation; and

operation control means for controlling operation of the robot depending on the determined desired gait.

23. An apparatus for controlling a legged mobile robot according to claim 22, characterized in that said desired landing orientation comprises an orientation about a vertical axis, and the landing orientation estimated by

said foot landing position/orientation estimating means includes at least an orientation about a vertical axis.

24. An apparatus for controlling a legged mobile robot according to claim 22, characterized in that said desired foot landing position/orientation determining means comprises means for determining the desired landing position and desired landing orientation corresponding to the next time's landing action and thereafter provisionally determining a self-dependent allowable landing range for the landing position of the foot to be landed in the next but one time's landing action based on the determined desired landing position and desired landing orientation and the mechanism-dependent limiting conditions of the robot, and means for correcting at least either one of the desired landing position and desired landing orientation corresponding to the next time's landing action in order to have a common region of at least the provisionally determined self-dependent allowable landing range corresponding to the next but one time's landing action and the next but one time's environment-dependent allowable range set by said first allowable landing range setting means for the next but one time's landing action, if said common region is not provided.

25. An apparatus for controlling a legged mobile robot according to claim 22, characterized in that said second allowable landing range setting means sets said

self-dependent allowable landing range based on a map or formula which is determined in advance as defining a relative allowable landing range of the foot to be landed in the next time's landing action, with respect to the foot landed in the landing action.

26. An apparatus for controlling a legged mobile robot according to claim 4, characterized in that said legged mobile robot comprises a biped mobile robot having two legs, and said desired landing position for the foot comprises a point having a predetermined positional relationship to each foot and a position of a representative point which is determined in advance with respect to each foot such that the representative point with respect to each foot becomes an identical point for both feet when said robot is upstanding in a predetermined reference symmetrical posture.

27. An apparatus for controlling a legged mobile robot according to claim 26, characterized in that said representative point comprises a point set up near the heel or toe of each foot.

28. A footstep determining apparatus for determining a desired landing position and desired landing orientation for the foot of a leg to be landed in each landing action of a legged mobile robot which is movable by repeating lifting and then landing actions of each of a plurality of legs, comprising:

desired path setting means for setting a desired footstep path for said robot;

wherein the desired landing position and desired landing orientation for the foot to be landed in each landing action of said robot are determined based on the desired landing position and desired landing orientation for the foot landed in at least the preceding landing action, and said desired footstep path.

29. A footstep determining apparatus for a legged mobile robot according to claim 28, characterized in that said desired landing orientation comprises an orientation about a vertical axis.

30. A footstep determining apparatus for a legged mobile robot according to claim 28, characterized in that when a desired landing position and desired landing orientation for the foot to be landed in each landing action of the robot is to be determined, a combination of a desired landing position and desired landing orientation for the foot in the landing action is determined in a self-dependent allowable landing range which is determined under mechanism-dependent limiting conditions of the robot itself, which include an interference between the leg making the landing action and the other leg.

31. A footstep determining apparatus for a legged mobile robot according to claim 30, characterized in that said self-dependent allowable landing range which is



used to determine a desired landing position and desired landing orientation for the foot to be landed in an Nth landing action of the robot is set based on a map or formula which is determined in advance as defining a relative allowable landing range of the foot to be landed in the Nth landing action with respect to the foot to be landed in an (N-1)th landing action.

32. A footstep determining apparatus for a legged mobile robot according to claim 28, comprising:

desired landing position/orientation provisionally determining means for, when a desired landing position and desired landing orientation for the foot to be landed in an Nth landing action of the robot is to be determined, provisionally determining a desired landing position and desired landing orientation of the foot to be landed in several landing actions ahead including said Nth landing action, based on a desired landing position and desired landing orientation for the foot to be landed in an (N-1)th landing action and said desired footstep path;

provisional desired gait determining means for determining a provisional desired gait of the robot which defines at least said Nth landing action using the provisionally determined desired landing position and desired landing orientation in the several landing actions ahead; and

desired landing position/orientation correcting means for determining whether a desired ZMP corresponding to the determined provisional desired gait satisfies a predetermined limiting condition or not, and, if the desired ZMP does not satisfy the predetermined limiting condition, correcting at least either one of the desired landing position and desired landing orientation of the foot to be landed in said Nth landing action, thereby to determine the desired landing position and desired landing orientation of the foot to be landed in said Nth landing action.

33. A footstep determining apparatus for a legged mobile robot according to claim 28, characterized in that said legged mobile robot comprises a biped mobile robot having two legs, said desired landing position for the foot comprises a point having a predetermined positional relationship to each foot and a desired position for a representative point which is determined in advance with respect to each foot such that the representative point with respect to each foot becomes an identical point for both feet when said robot is upstanding in a predetermined reference symmetrical posture, and said desired footstep path comprises a path to be approached by said representative point.

34. A footstep determining apparatus for a legged mobile robot according to claim 33, characterized in

that said representative point comprises a point set up near the heel or toe of each foot.

35. A footstep determining apparatus for determining a desired landing position and desired landing orientation for the foot of a leg to be landed in each landing action of a legged mobile robot which is movable by repeating lifting and then landing actions of each of a plurality of legs, comprising:

allowable foot landing range setting means for setting an environment-dependent allowable landing range determined under environmental conditions in which the robot moves, which is an allowable range of combinations of landing positions and landing orientations of feet landed in each landing actions of the robot;

wherein a combination of the desired landing position and desired landing orientation for the foot to be landed in each landing action of said robot is determined based on the desired landing position and desired landing orientation for the foot landed in at least the preceding landing action, and said environment-dependent allowable landing range.

36. A footstep determining apparatus for a legged mobile robot according to claim 36, characterized in that said desired landing orientation comprises an orientation about a vertical axis.

37. A footstep determining apparatus for a legged mobile robot according to claim 35, characterized in that when a desired landing position and desired landing orientation for the foot to be landed in each landing action of the robot is to be determined, a combination of a desired landing position and desired landing orientation for the foot in the landing action is determined in a common region of a self-dependent allowable landing range determined under mechanism-dependent limiting conditions of the robot itself, which include an interference between the leg making the landing action and the other leg, and the environment-dependent allowable landing range corresponding to the landing action, based on said self-dependent allowable landing range and said environment-dependent allowable landing range.

38. A footstep determining apparatus for a legged mobile robot according to claim 37, characterized in that said self-dependent allowable landing range which is used to determine a desired landing position and desired landing orientation for the foot to be landed in an Nth landing action of the robot is set based on a map or formula which is determined in advance as defining a relative allowable landing range of the foot to be landed in the Nth landing action with respect to the foot to be landed in an (N-1)th landing action.

39. A footstep determining apparatus for a legged mobile robot according to claim 37, comprising:

desired landing position/orientation provisionally determining means for, when a desired landing position and desired landing orientation for the foot to be landed in an Nth landing action of the robot is to be determined, provisionally determining a desired landing position and desired landing orientation of the foot to be landed in several landing actions ahead including said Nth landing action, based on a desired landing position and desired landing orientation for the foot to be landed in an (N-1)th landing action, said environment-dependent allowable landing range corresponding to each of the several landing actions ahead, and said self-dependent allowable landing range corresponding to each of the several landing actions ahead;

provisional desired gait determining means for determining a provisional desired gait of the robot which defines at least said Nth landing action using the provisionally determined desired landing position and desired landing orientation in the several landing actions ahead; and

desired landing position/orientation correcting means for determining whether a desired ZMP corresponding to the determined provisional desired gait satisfies a pre-determined limiting condition or not, and, if the desired

ZMP does not satisfy the predetermined limiting condition, correcting at least either one of the desired landing position and desired landing orientation of the foot to be landed in said Nth landing action, thereby to determine a combination of the desired landing position and desired landing orientation of the foot to be landed in said Nth landing action.

40. A footstep determining apparatus for a legged mobile robot according to claim 35, characterized in that said legged mobile robot comprises a biped mobile robot having two legs, and said desired landing position for the foot comprises a point having a predetermined positional relationship to each foot and a desired position for a representative point which is determined in advance with respect to each foot such that the representative point with respect to each foot becomes an identical point for both feet when said robot is upstanding in a predetermined reference symmetrical posture.

41. A footstep determining apparatus for a legged mobile robot according to claim 40, characterized in that said representative point comprises a point set up near the heel or toe of each foot.